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PRELIMINARY ORBITS OF FOUR BINARY STARS¹

BY R. G. AITKEN

In the early days of double star astronomy the great question to be answered was: "What is the law of the force which governs the observed motions in stellar systems?" Theories of the motion based upon the assumption that the controlling force was identical with that described by Newton's law of gravitation had, indeed, been formulated soon after the appearance of Herschel's epoch-making paper, in 1803, "Account of the Changes that have happened during the last Twenty-five Years, in the relative Situation of Double-stars; with an Investigation of the Cause to which they are owing;" it remained to test their adequacy by accurate measures of a large number of systems. Such measures were accumulated by the labors of many eminent astronomers in the course of the nineteenth century, and it has long been known from them that the law of gravitation permits us to represent the observed motion and predict the future motion in binary star systems within the limits of the unavoidable errors of measurement. In the few cases in which periodic groupings of the apparent positions indicate systematic departure from pure elliptic motion, it has been possible to find adequate explanation in the assumption that one or the other of the visible stars of the pair is attended by an unseen companion and the correctness of this assumption is now not questioned. In fact, in the case of *Epsilon Hydrae*, its correctness has been demonstrated. Schiaparelli, in 1888, discovered that the principal star of the Struve pair was itself a close unequal pair. In 1903 I computed the orbit of this close pair and Seeliger soon afterward showed that its motion in its fifteen-year-period orbit fully accounted for the observed irregularities in the motion of the wider long-period Struve system.

All this does not mean that it is no longer necessary or desirable to measure the visual binary stars; it simply means that interest has shifted largely from the motion in the particular system and the laws governing it to the information we can gain from a comparative study of the orbits of many systems as to the origin of the binary stars and their relation to single star systems. Of at least equal importance is the knowledge of the masses of the stars which

¹Read at the Seattle meeting of the Pacific Division A. A. A. S. Details of the computations will be printed later elsewhere.

we can obtain directly only from the visual binary systems whose orbits are known and whose parallax has been measured.

For such investigations the orbit elements are not all of equal importance and an accurate knowledge of them all, tho desirable, is not essential. So far as we can judge at present, the time of periastron passage, the orientation of the orbit plane and of the orbit in its plane have little bearing upon questions of binary star evolution; the eccentricity of the orbit, the period of revolution and the length of the major semi-axis are the three important elements. The last two are the only ones needed for mass determinations. It is worth while, therefore, to compute approximate orbits of binary stars which promise fair values of these three elements, even tho the data do not suffice for reliable determinations of all the elements. The orbits I present today, as will appear, fall into this category of approximate solutions.

The first two systems— Σ 412 and β 552—have been well observed over relatively short arcs, but we have earlier estimates and other data which help to define the apparent ellipse in each case. The former system was discovered by Struve in 1830 when the two components, of equal brightness, were separated by $0''.7$. It has been observed regularly ever since and the companion, to date, has described an arc of 173° , with distances slowly diminishing to a minimum of $0''.2$ about the year 1915 and since then very slowly increasing. Herschel listed a distant companion in 1781, but did not see the close pair. This fact leads to the inference that the angular separation at that time was but little, if at all, greater than in 1830, when Struve discovered it. On this hypothesis the apparent ellipse is defined within quite narrow limits and the following elements result:

Revolution period	270 years
Date of periastron passage	1917.3
Eccentricity	0.555
Major semi-axis	$0''.49$
Nodal point	97°
Inclination of orbit plane	41°
Angle between nodal point and periastron point	348°
Position angles decreasing with the time.	

According to Boss, the system has a centennial proper motion of $3''.5$ in 141° , and this value finds confirmation in the measures connecting the Herschel companion with the binary. That companion is, therefore, probably an independent star. The eccentricity is rather smaller than might be expected of a star with so long a

period; it is, in fact, close to the average value for all known visual binary star orbits. The parallax is unknown, but if we assume the mass to be twice that of the Sun, the computed parallax is $0''.0086$, a result which seems reasonable for a star of its magnitude (5.9) and spectral class (A2).

The orbit of β 552 resembles that of Σ 412 in its eccentricity and in the size of the *apparent* ellipse, but the period of revolution is only one-third as long. The well observed part of the orbit extends over but 120° but, fortunately, we have also the early estimates of position made by Burnham in 1874 and 1877. If these are even approximately correct the available arc is nearly 287° and the orbit is now quite determinate. Elements were indeed computed by See in 1908 but these fail to represent the later motion². The elements now obtained are:

Period.....	.86 years
Periastron.....	1886.35
Eccentricity.....	0.51
Major semi-axis.....	0".56
Nodal point.....	145°.8
Inclination.....	39.35
Angle between node and periastron.....	309.6
Angles increasing.	

We have values of the parallax of the system determined both by the photographic and by the spectroscopic method, the former being $+0''.014$ (absolute), the latter, $+0''.027$. Using the elements just given these lead to the mass values $8.7 \odot$ and $1.2 \odot$, respectively. Now the spectral class of this 6.7 magnitude star is F5 according to Miss Cannon, F6 according to Adams, and evidence from several sources leads us to believe that stars of this class are not likely to be of very great mass. Recalling also the fact that the average mass value of those binaries for which this value is well determined is about $1.7 \odot$, I incline to the opinion that the spectroscopic parallax is nearer the truth than the photographic one.

²After this paper had been written, I received the March, 1920, number of the *Monthly Notices R. A. S.* containing Mr. J. Jackson's paper on "The Orbits of 20 Double Stars." Two of these stars are Σ 412 and β 552 and it is of interest to compare Mr. Jackson's values of the period, major semi-axis and eccentricity of these systems, derived from measures to 1913 inclusive, with those I have computed from measures to 1920 inclusive. Mr. Jackson's values are as follows:

	Period	216.9 years	88.2 years
Major semi-axis.....	0".407	0".627	
Eccentricity.....	0.545	0.519	

The eccentricities agree almost precisely with those given above; the period and major semi-axis are in the one case smaller and in the other larger than my values but the two elements in each case vary in the same sense so that the hypothetical parallaxes are in close agreement with those found from my elements.

This raises an interesting question: "May we some day hope to use our knowledge of stellar masses as one criterion in estimating the systematic errors of different sets of parallax values?" It would obviously be unsafe to generalize upon the basis of the data now available, but even now I am of opinion that in particular cases we may use the resulting mass of a binary system to aid us in our estimate of the reliability of its published parallaxes. The system β 395 is a case in point. Flint, some years ago, from meridian circle observations, found the absolute parallax to be $+0''.36$. The orbit elements of this binary are quite accurately determined, the period being 25.0 years, the major semi-axis $0''.66$. Combined with Flint's parallax, these data lead to the very improbable mass of only 0.009 \odot . There is no question here but that the spectroscopic parallax, $+0''.066$, with its corresponding mass of 1.6 \odot , is by far the more accurate.

The other two orbits which I wish to present differ in almost every particular from the two already described and at the same time are in striking contrast to each other in their eccentricity. β 1185 was discovered by Burnham with the 36-inch in 1890 and except for measures on four nights in 1896 by Schiaparelli has since then, so far as I know, been measured only by me. The maximum separation of the two components is less than a quarter of a second of arc, and, at minimum, the star appears absolutely round when viewed with the highest powers. The measures also show that the orbit plane is inclined at a high angle to the plane of projection. When the distance is near its maximum the difference in the brightness of the two components is quite appreciable and the quadrant determinate; moreover, the measures can only be harmonized on the assumption that the companion is now in the position it occupied at discovery in 1890 and that in the years 1906-1911 the elongation was in the opposite quadrant and was slightly greater. We therefore have the elements:

Period.....	28.9 years
Periastron time.....	1917.8
Eccentricity.....	0.19
Major semi-axis.....	$0''.23$
Nodal point.....	$22^\circ.5$
Inclination.....	77°
Angle between node and periastron.....	$310^\circ.4$
Angles decreasing.	

The period and eccentricity are, I think, very nearly correct; the uncertainty in the value of the major semi-axis is a little greater,

but the value given I regard as a fair approximation. It appears that the orbit is more nearly circular than that of the planet *Mercury*. Only seven other visual binaries are known with orbits so slightly elliptic. The spectral class is G₀, the photometric magnitude 7.7. Assuming a mass of $2 \odot$ the elements give a parallax of $+0''.019$. As the mass is probably not greater than the value assumed, this hypothetical parallax may be considered as the minimum to be expected.

The fourth system OΣ₃₄₁, is one of quite unusual interest. Discovered in 1843, the scattered positive observations to 1886 indicated relative fixity of the two components at an angular separation of about $0''.45$. No measures were made in the intervals 1852-1865, 1872-1882, and 1886-1898, but Otto Struve, in 1877, reported that he could see no trace of the companion. No significance was attached to this report, however, until early in 1898, when Hussey, then engaged upon the remeasurement of all of the Otto Struve stars, also failed to see the companion. At his request I examined the star at that time and found it single. Later in the same year Hussey was able to detect a very slight elongation and in 1899 it was clearly double. The distance increased, at first rapidly, then more gradually, until it reached a maximum of nearly $0''.5$ about the year 1910. I have followed the system carefully since 1900, always using in its identification the chart prepared by Hussey and myself in 1898. In 1914 I found that the distance had decreased to $0''.34$; in 1916, to $0''.24$; in 1917, to $0''.15$ or less. In 1918 elongation was barely perceptible, but in 1919, the measures gave $0''.19$, and the distance is now fully $0''.28$. The components differ in brightness by at least three-quarters of a magnitude and there is no question but that the companion is now in the same quadrant as in 1916 and in 1900.

From these facts and the further one that the variation in position angle is small, it is clear that the orbit is one of extreme eccentricity lying at a high angle of inclination to the plane of projection. The period of revolution is very definitely known from the apparent conjunctions of 1898 and 1918, and the time of periastron passage cannot differ by more than a fraction of a year from that of apparent conjunction. The eccentricity, too, is well determined, but the other elements are relatively uncertain. The major semi-axis may have any value between $0''.25$ and $0''.30$.

The best solution I could obtain by graphical methods and later arbitrary variation of the elements gave the following results:

Period	19.75 years
Periastron time	1917.85
Eccentricity	0.96
Major semi-axis	0".30
Nodal point	104°
Inclination	77° 5'
Angle between node and periastron	149°
Angles increasing.	

The adopted period fits the early observations very well, the elongations coming at the times when positive observations were made, the conjunctions at times for which we have no measures. In particular, one conjunction coincides closely with the date in 1877 when Otto Struve could see no trace of the companion.

The spectral class is G0, the BD magnitude 7.5. Assuming, once more, a mass of $2 \odot$, the parallax will be $+0".0326$ if the major semi-axis be taken as $0".30$, and $+0".0272$ if we adopt what appears to be the minimum possible value of $0".25$. The parallax should therefore be measurable with considerable accuracy.

The chief interest in the system, however, attaches to the eccentricity, 0.96. For only one other system has so high a value been found. This is *Zeta Bootis*, for which Hertzsprung and I, independently, found about three years ago that the law of areas could best be satisfied by assuming extremely rapid angular motion at the time of approximate conjunction and an eccentricity of 0.96 to correspond. The two components of *Zeta Bootis* are very nearly of equal brightness and the quadrant always indeterminate. The interpretation of the measures just given may therefore be open to some question tho I believe it to be correct. But in the case of $\sigma 341$, as I have pointed out, the quadrant is never in doubt when the two components are separately visible and the general form of the apparent ellipse is therefore well determined. A value of e as low as 0.94 definitely fails to represent the observations.

Now it has repeatedly been shown, and most recently and convincingly by Jeans, that so great an eccentricity cannot be developed by the internal forces of a binary system which has originated by fission of a single mass. To account for it we are driven to a search for adequate external forces or to the conclusion that such systems were evolved thru some process other than that of fission. We are being led to consider seriously the hypothesis that there are

two (or more) classes of binary systems which have been developed by entirely different evolutionary processes. A number of interesting suggestions along these lines have been made, but it is my opinion that we must wait for more data before we can accept any theory as more than a working hypothesis. It is the desire to secure such data that provides the chief incentive for the observation of the visual binary stars at the present time.

June 3, 1920.